Available online at www.sciencedirect.com
SCIENCE DIRECT®
Ultrasonics 43 (2005) 505–507
Ultrasonics
www.elsevier.com/locate/ultras

Short communication

Schlieren photography to study sound interaction with highly absorbing materials

Nico F. Declercq [a,*], Joris Degrieck [a], Oswald Leroy [b]

[a] Soete Laboratory, Department of Mechanical Construction and Production, Faculty of Engineering, Ghent University, Sint Pietersnieuwstraat 41, B-9000 Gent, Belgium
[b] Interdisciplinary Research Center, Katholieke Universiteit Leuven Campus Kortrijk, E. Sabbelaan 53, 8500 Kortrijk, Belgium

Received 21 June 2004; accepted 12 January 2005
Available online 26 January 2005

Abstract

Strong absorption of sound is often caused by the conversion of sound energy into heat. When this happens, it is not possible to study the interaction of sound with the absorbing material by means of reflected sound characteristics, because there is no reflected sound. Detecting for example the distance that sound travels in a strongly absorbing material, can be done by heat detection systems. However, the presence of temperature detectors in such materials interferes with the sound field and is therefore not really suitable. Infrared measurements are a possible option. Another option is the use of Schlieren photography for simultaneous visualization of sound and heat. This technique is briefly outlined with a 3 MHz sound beam incident on a highly absorbing sponge.

PACS: 43.35.Sx; 43.20.Hq
Keywords: Schlieren photography; Sound absorption; Heat

1. Introduction

Schlieren photography is based on the acousto-optic effect [1–5] and is important when ultrasound is to be visualized [6–10]. In a Schlieren experiment, a wide beam of coherent laser light propagates through a transparent medium in which ultrasound propagates. The presence of sound generates a light-diffraction grating which is caused by the spatially periodically varying refractive index which in its turn is caused by traversing soundwaves. Hence light is diffracted into several spatial orders [1–5]. Since only orders different form zero deviate from light that is not diffracted, the zero order field must be eliminated in order to visualize the presence of sound by means of the diffracted light. The obtained light is then projected on a screen and can be used to visualize ultrasound.

However, if an inhomogeneity in the refractive index is present due to other effects, it may also be visible on a Schlieren picture. The visualization of heat often occurs in other scientific areas by means of Schlieren photography as well [11–16]. Nevertheless, as far as we know, the simultaneous visualization of sound and sound induced heat, has not been reported yet.

2. Experimental setup

The experimental setup is sketched in Fig. 1. A strongly absorbing sponge is glued on an iron plate and is immersed in water at approximately 20 °C. A 1.6 W sound beam of 1 cm physical beam width and

* Corresponding author. Tel.: +32 9 264 3436; fax: +32 9 264 3587.
E-mail addresses: nicof.declercq@ugent.be, declercq@ieee.org (N.F. Declercq).

0041-624X/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.ultras.2005.01.001

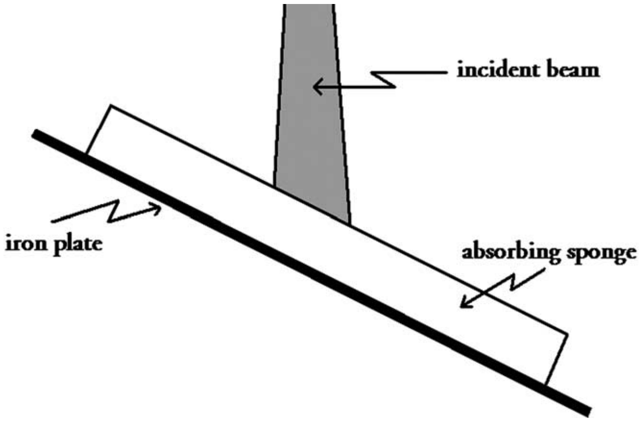

Fig. 1. Experimental setup. An incident ultrasonic beam impinges a highly absorbing sponge.

having a frequency of 3 MHz impinges the sponge. No reflected sound is visible due to the strong sound absorption. The sponge forms an angle with the incident beam. The angle is chosen randomly since the described effect occurs at each angle. Nevertheless the distance that sound propagates in the sponge can be angle dependent. The sound emitter is turned on for approximately 1 min after which it is turned off. The coherent light that is used to form the Schlieren pictures is emitted by a '633 nm/20 mW' laser apparatus.

3. Schlieren pictures

Fig. 2a–i show Schlieren pictures coming from the experimental setup described above. The sponge is impinged with sound for approximately 1 min. Then the sound emitter is turned off while the Schlieren image is continued to be observed. In Fig. 2a, the situation is shown an instant after the sound emitter is turned on. It is seen that no reflection occurs. This is due to the strong absorption of sound by the sponge. Fig. 2a–c show the situation as time passes. It is seen that heat is formed on the spot of incidence and that this heat zone 'grows' slowly. Fig. 2d shows the situation right after the incident sound beam is turned off. It is seen that the surface remains hot for a while. This hot zone diminishes slowly as is seen in Fig. 2d–i. Meanwhile, the formation of a heat convection cell is visible in Fig. 2e. This cell rises slowly in Fig. 2f, tends to tear itself away in Fig. 2g and dissolves completely in Fig. 2h. The situation after approximately 30 s is seen in Fig. 2i. Some instants later, no hot zone is visible anymore.

4. Conclusion and prospects

It is shown that the formation and the evolution of heat due to sound absorption is visible on Schlieren pic-

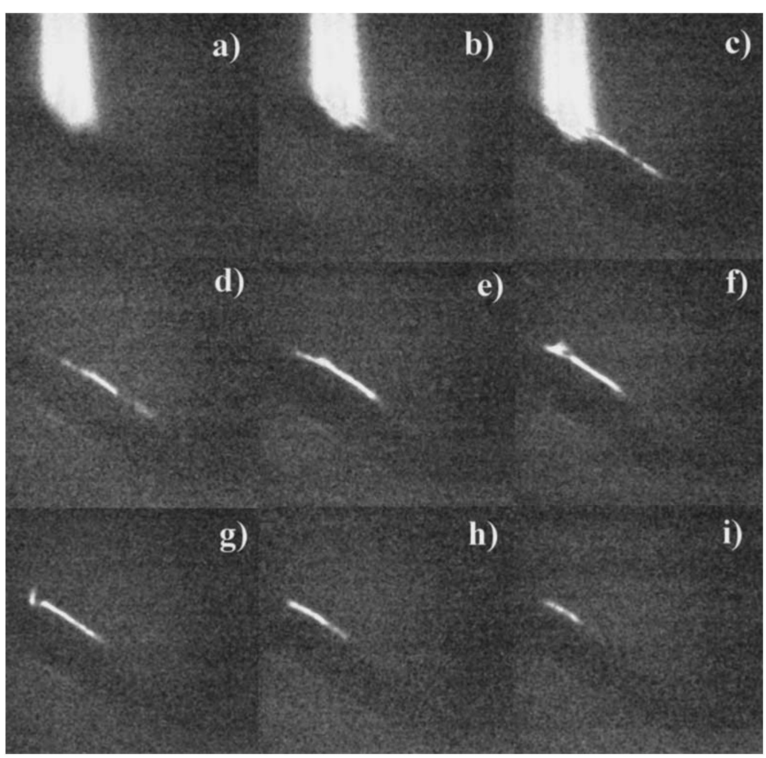

Fig. 2. Sequence of Schlieren pictures of a sound beam impinging a sponge and the generated heat. a–c show the situation while the sound source is turned on and corresponds approximately to a period of 60 s, whereas d–i show the evolution after the sound source has been turned off and span a period of approximately 30 s.

tures simultaneously with an incident sound beam. Further research is necessary to build a theory that describes the effect correctly. The method could possibly be used to find critical angles in the absence of a reflected beam.

Acknowledgments

The authors wish to thank 'The Flemish Institute for the Encouragement of the Scientific and Technological Research in Industry (IWT)' for sponsoring this research. The reviewers are also acknowledged for their guidance in reducing this paper to its essentials.

References

[1] W. Hereman, R. Mertens, F. Verheest, O. Leroy, J.M. Claeys, E. Blomme, Interaction of light and ultrasound: acousto-optics, Phys. Mag. 6 (4) (1984) 213–245.

[2] E. Blomme, O. Leroy, Diffraction of light by ultrasound: finite analytical expressions for the spectra up to order 3, Acustica 57 (1985) 168–174.

[3] V.F. Humphrey, S.M. Knapp, C. Beckett, Visualisation of the resonances of a fluid-filled cylindrical shell using a low frequency Schlieren system, in: O. Leroy, M.A. Breazeale (Eds.), Physical Acoustics, Plenum Press, New York, 1991.

[4] A. Korpel (Ed.), Selected Papers on Acousto-Optics, SPIE Milestone Series, Vol. MS 16, 1990.

[5] A. Korpel, Acousto-Optics, second ed., Marcel Dekker Inc., 1997.

[6] P.A. Chinnery, V.F. Humphrey, On the overlapping acoustic resonances of a fluid-filled cavity: Schlieren visualization of an insonified circular-cylindrical shell, J. Acoust. Soc. Am. 102 (3) (1997) 1383–1387.

[7] T. Tuziuti, T. Kozuka, H. Mitome, Evaluation of source sound pressure of an ultrasonic transducer using Schlieren visualization, J. Acoust. Soc. Am. 98 (5) (1995) 2876.

[8] T.H. Neighbors, W.G. Mayer, H.J. Ruf, Acousto-optic imaging of focused ultrasound pressure fields, J. Acoust. Soc. Am. 98 (3) (1995) 1751–1756.

[9] M. de Billy, J.F. Piet, S. Mahaut, G. Quentin, Ray theory applied to the internal caustic identification of liquid cavities acoustically insonified, J. Acoust. Soc. Am. 95 (2) (1994) 1143–1146.

[10] W.E. Moore, J.A. Bucaro, Measurement of acoustic fields using Schlieren and holographic techniques, J. Acoust. Soc. Am. 63 (1) (1978) 60–67.

[11] A.K. Agrawal, N.K. Butuk, S.R. Gollahalli, D. Griffin, Three-dimensional rainbow Schlieren tomography of a temperature field in gas flows, Appl. Optics 37 (3) (1998) 479–485.

[12] X. Qin, X.D. Xiao, I.K. Puri, S.K. Aggarwal, Effect of varying composition on temperature reconstructions obtained from refractive index measurements in flames, Combust. Flame 128 (1–2) (2002) 121–132.

[13] G. Tanda, F. Devia, Application of a Schlieren technique to heat transfer measurements in free-convection, Exp. Fluids 24 (4) (1998) 285–290.

[14] Y. Marchesse, Y. Gervais, H. Foulon, Optical measurements of the temperature in a supersonic jet, AIAA J. 41 (3) (2003) 470–475.

[15] B.W. Albers, A.K. Agrawal, Schlieren analysis of an oscillating gas-jet diffusion flame, Combust. Flame 119 (1–2) (1999) 84–94.

[16] G. Tanda, M. Misale, F. Devia, Experimental heat transfer from a vertical plate within a naturally ventilated cabinet, Heat Mass Trans. 36 (6) (2000) 511–516.